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Title: Benchmarking of FEHM Control Volume Finite Element Solver

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Benchmarking of FEHM Control Volume Finite Element Solver

The 8th International Congress on Environmental Geotechnics
10/30/2018

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INNOVATIVE GEO-MODELING SOFTWARE



SOILVISION SYSTEMS LTD. - EST. 1997



- Founded in 1997 in Saskatoon, Saskatchewan, Canada
- Offers limit equilibrium, finite element and soils database software
- Pioneered mainstream 3D limit equilibrium slope stability analysis
- Acquired by Bentley Systems Inc. in 2018

Outline

1. Introduction

- FEHM solver
- ***SVOFFICE™ 5/WR***

2. Benchmarking

- Case 1: Confined Flow Under a Dam
- Case 2: Well Pumping in Confined Aquifer (Theis)
- Case 3: Free Convection Cells
- Case 4: Water-Vapor Multiphase Heat and Mass Transfer

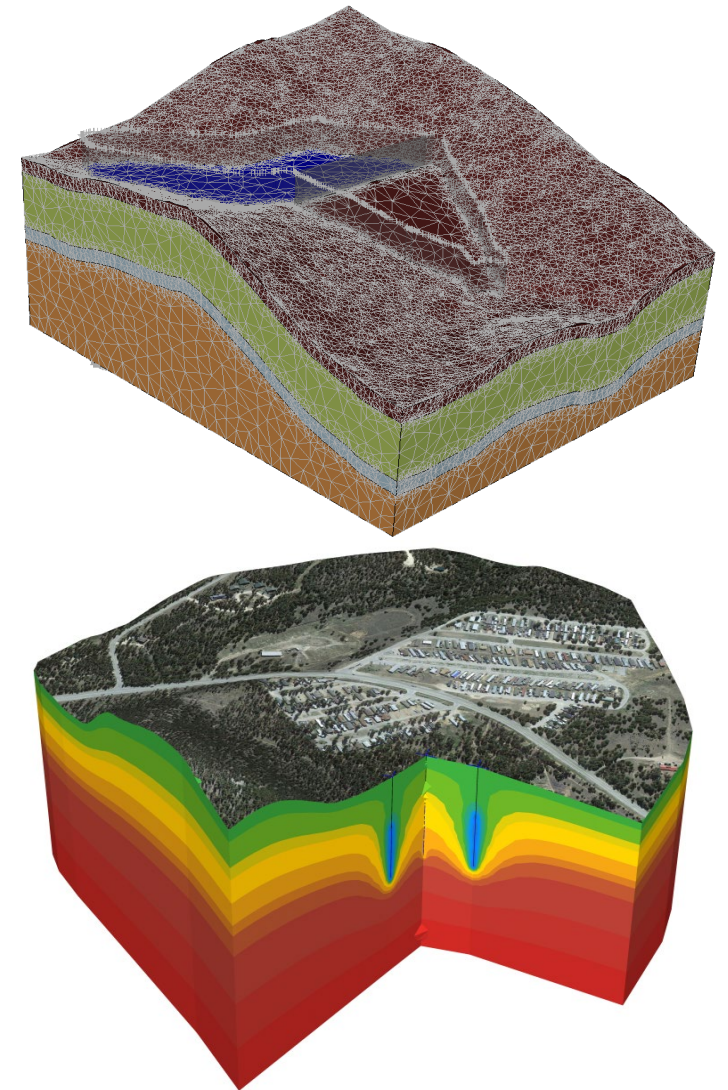
3. Ability to model field-scale systems

4. Summary

5. References

1. Introduction

- Numerical modeling of groundwater and geothermal problems has expanded in the past few years due to the increase in computational power and software.
- Problems with larger numbers of total nodes, with complex geology involving faulting, as well as coupling of multiple physical processes (geothermal, CO² sequestration) are now being attempted.



1. Introduction



FEHM solver

- Developed by Los Alamos National Laboratory (LANL) over 50 man-years of effort
- Capabilities*
 - ✓ Control Volume Finite Element (CVFE) method
 - ✓ Fully implicit, fully coupled Newton Raphson solution of nonlinear equations
 - ✓ 3D complex geometries with unstructured grids
 - ✓ Saturated and unsaturated media
 - ✓ Non-isothermal multi-phase flow of air, water
 - ✓ Double porosity/double permeability capabilities for fractured reservoir
 - ✓ Simulation of geothermal reservoirs
 - ✓ Multiple chemically reactive and sorbing tracers

* <https://fehm.lanl.gov/>

1. Introduction

SVOFFICE™ S/WR
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POWERED BY **FEHM**

- LANL and SoilVision Systems Ltd. have combined efforts to offer groundwater and geothermal numerical modeling solutions of larger and more complex systems.

*Under development



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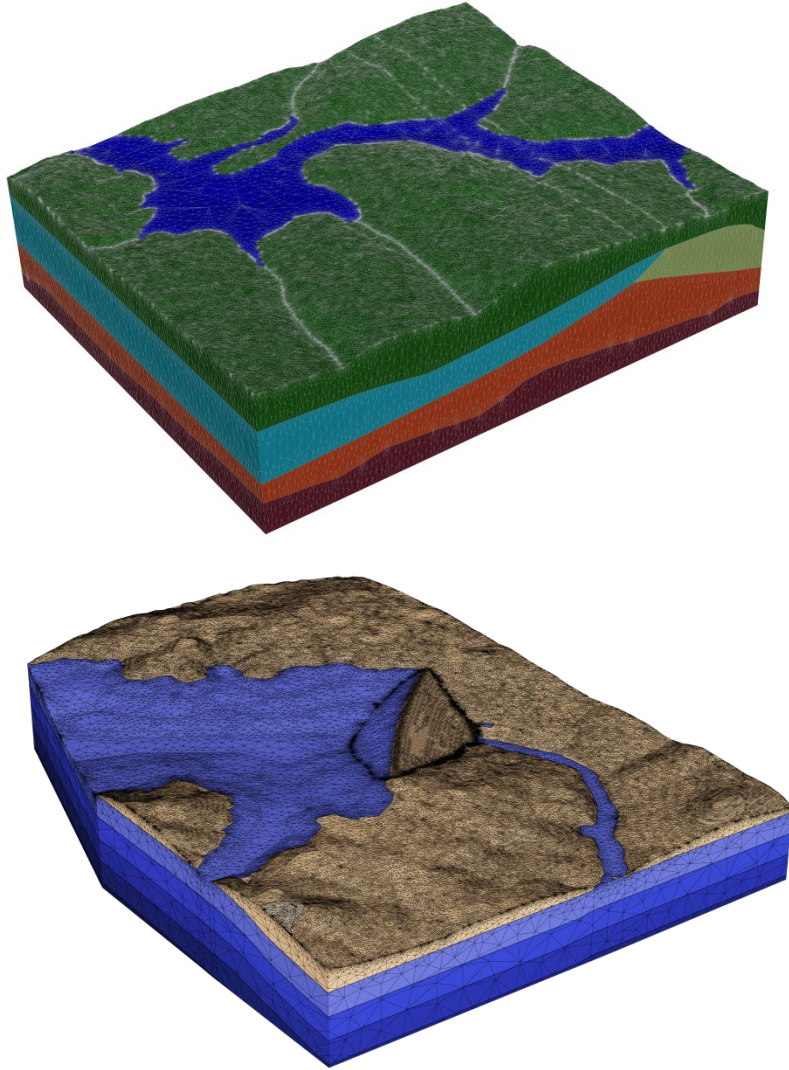


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1. Introduction



SVOFFICE™ 5/WR key features

- Large Regional Models: Efficiently create and analyze large regional numerical groundwater flow models with millions of nodes.
- Nonlinear Analysis: Stable analysis of nonlinear unsaturated models.
- Handle Complex Geometry: Model complex geometry including pinch-outs with automatic mesh generation.
- ***SVDESIGNER™*** Conceptual Modeling Module
- Automatic Mesh Generation and Manual Refinement.
- Easy to Use: Featuring a familiar user interface with easy to understand functions and redesigned icons.
- Import soil properties from the ***SVSOILS™*** database of over 6200 soils.

1. Introduction

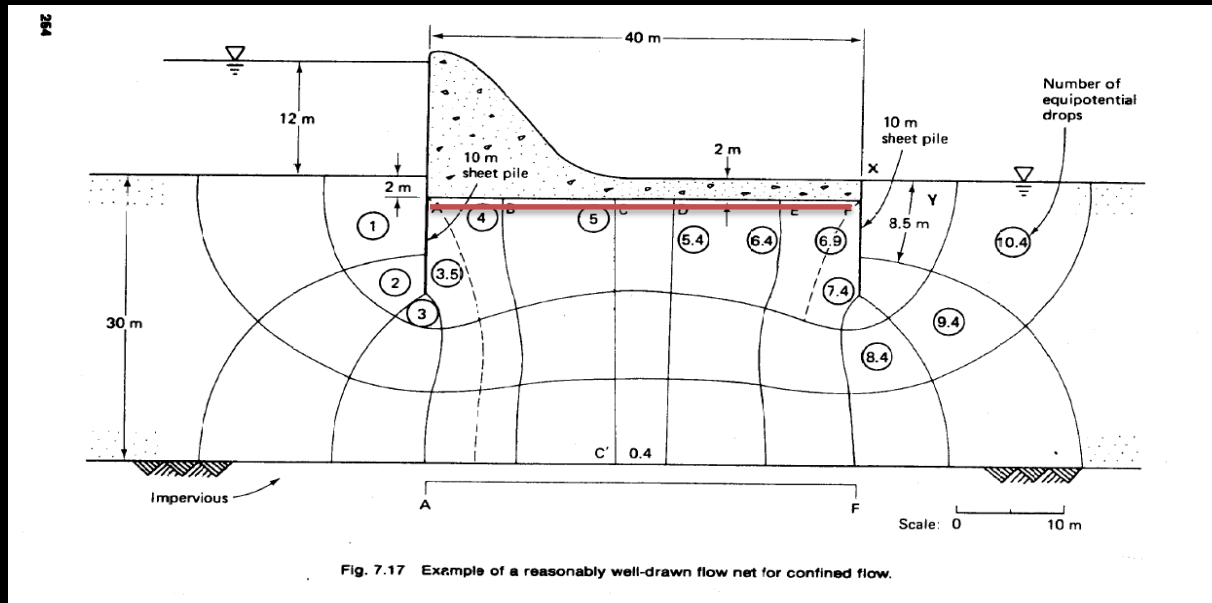
- This presentation shows the results of benchmarks created to test the performance of the new groundwater and geothermal modeling system.
- Performance of the system is discussed.
- The ability of the system to scale up to model field-scale systems will be discussed.



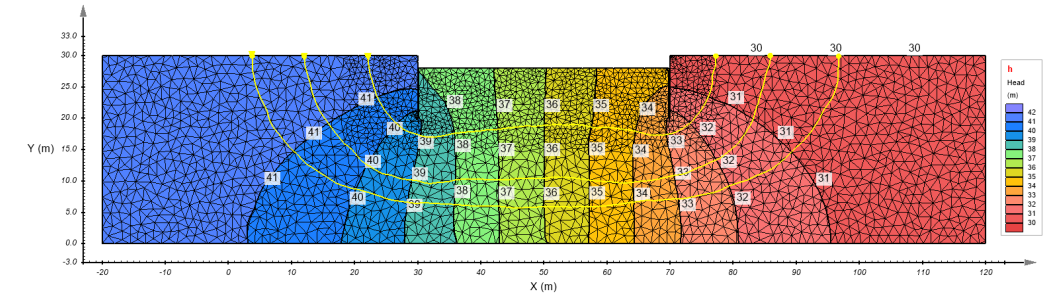
2. Benchmarking

Isothermal groundwater modeling

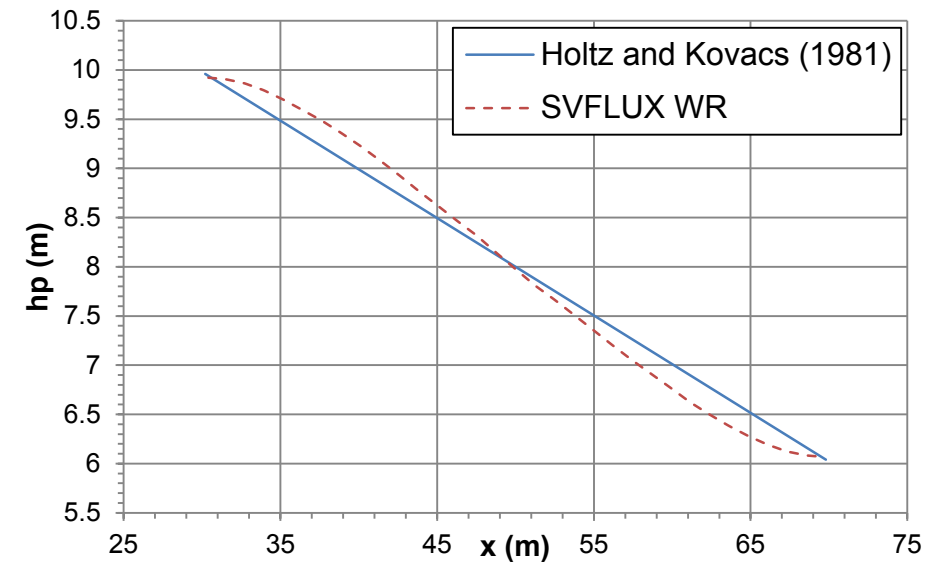
- Case 1: Confined Flow Under a Dam



Description of the example model
from Holtz and Kovacs (1981)



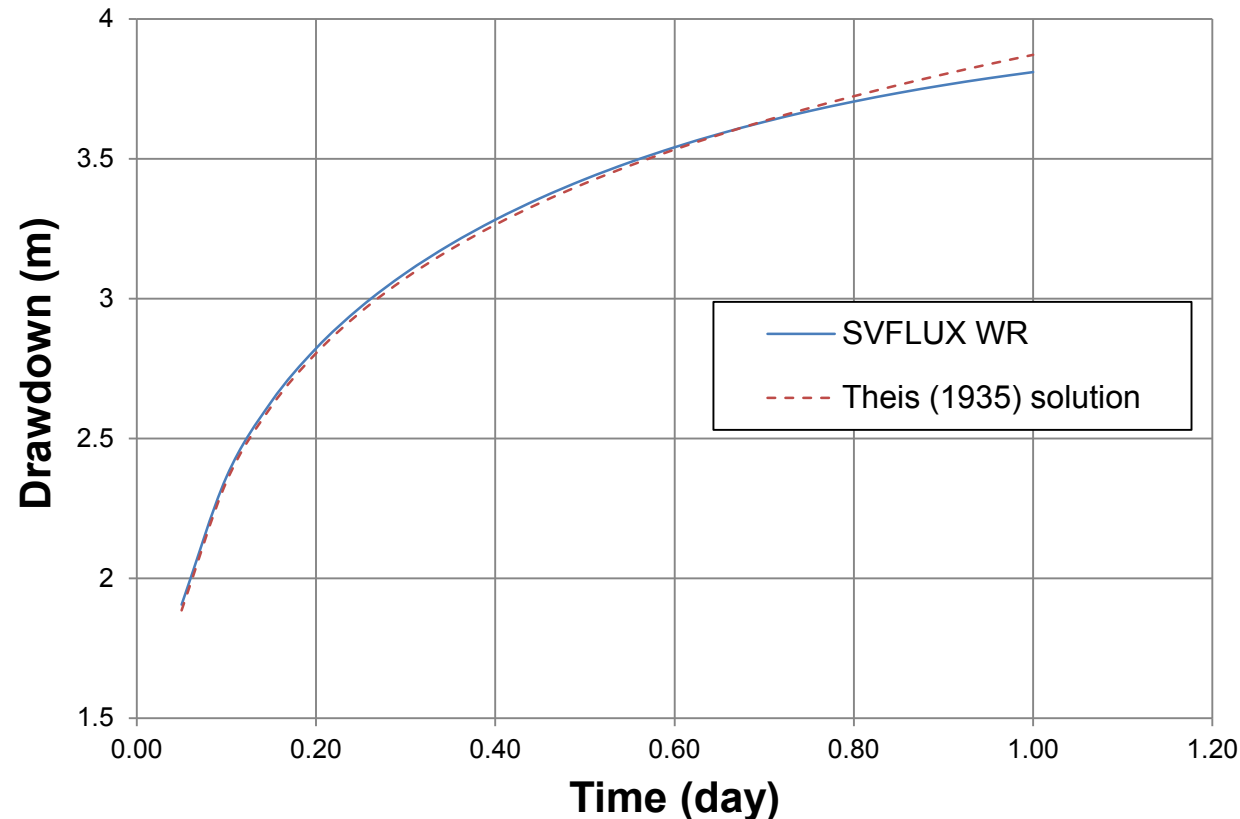
The contour of head (h) and select
streamlines under the dam



2. Benchmarking

Isothermal groundwater modeling

- Case 2: Well pumping in a confined aquifer (Theis (1935) solution)

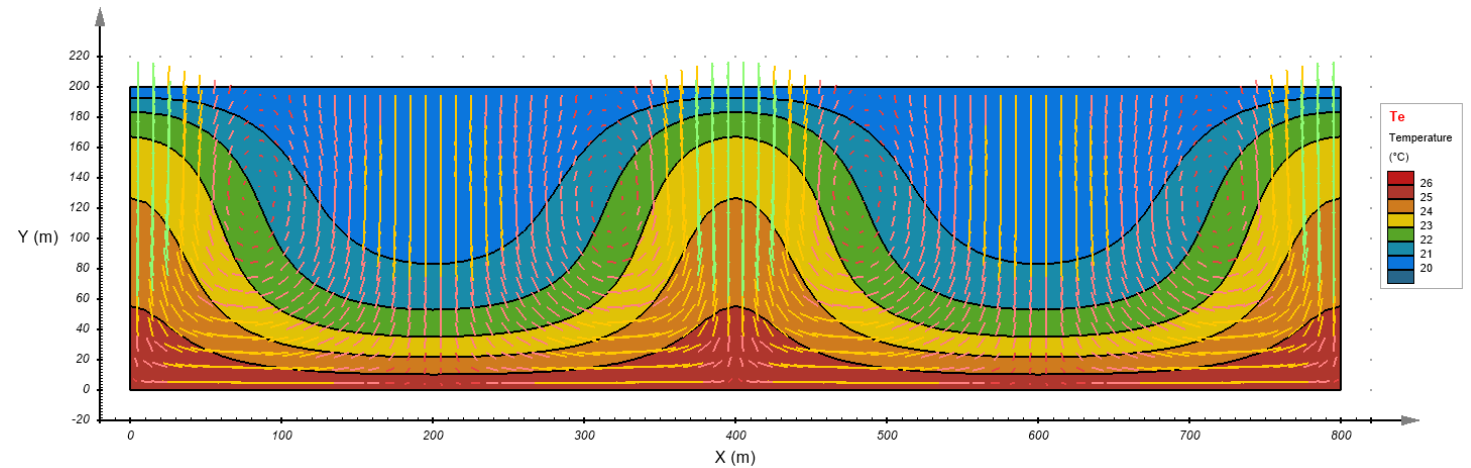
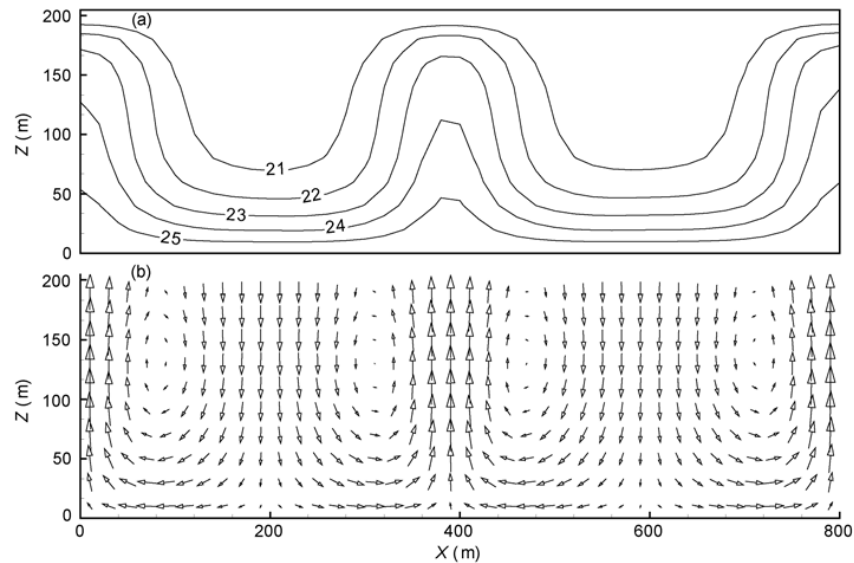


2. Benchmarking

Non-isothermal geothermal modeling

- Case 3: Free convection cells

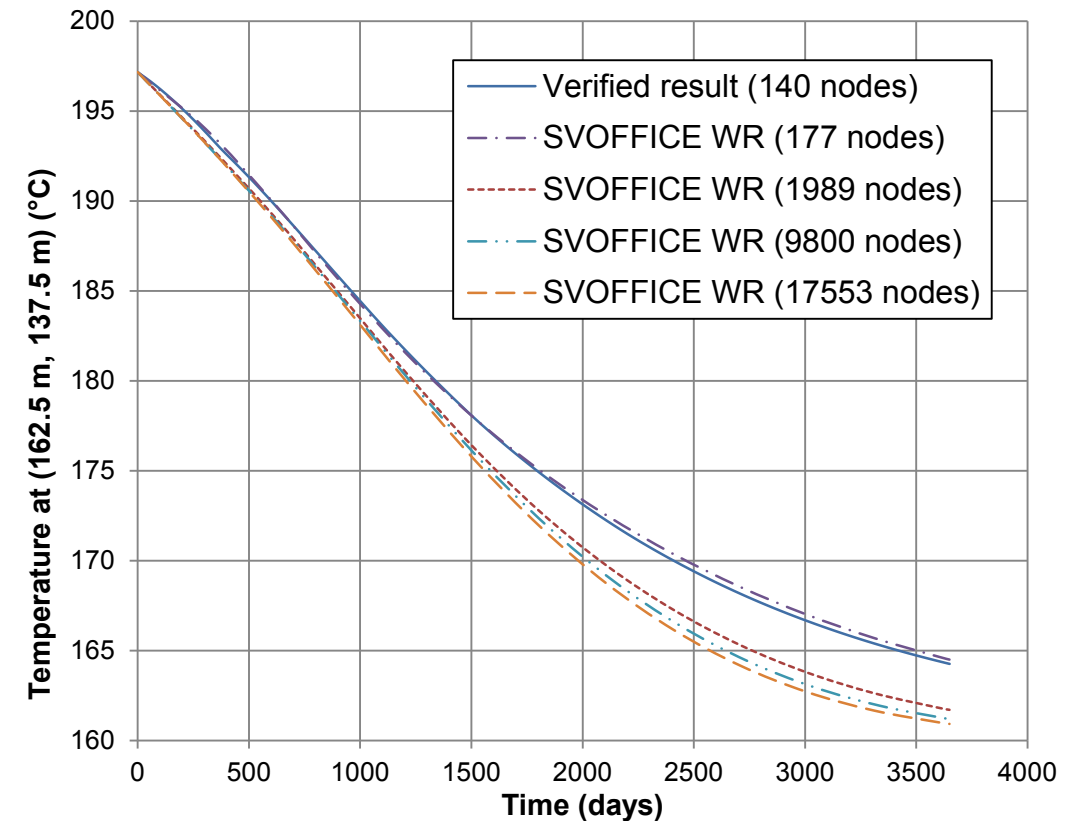
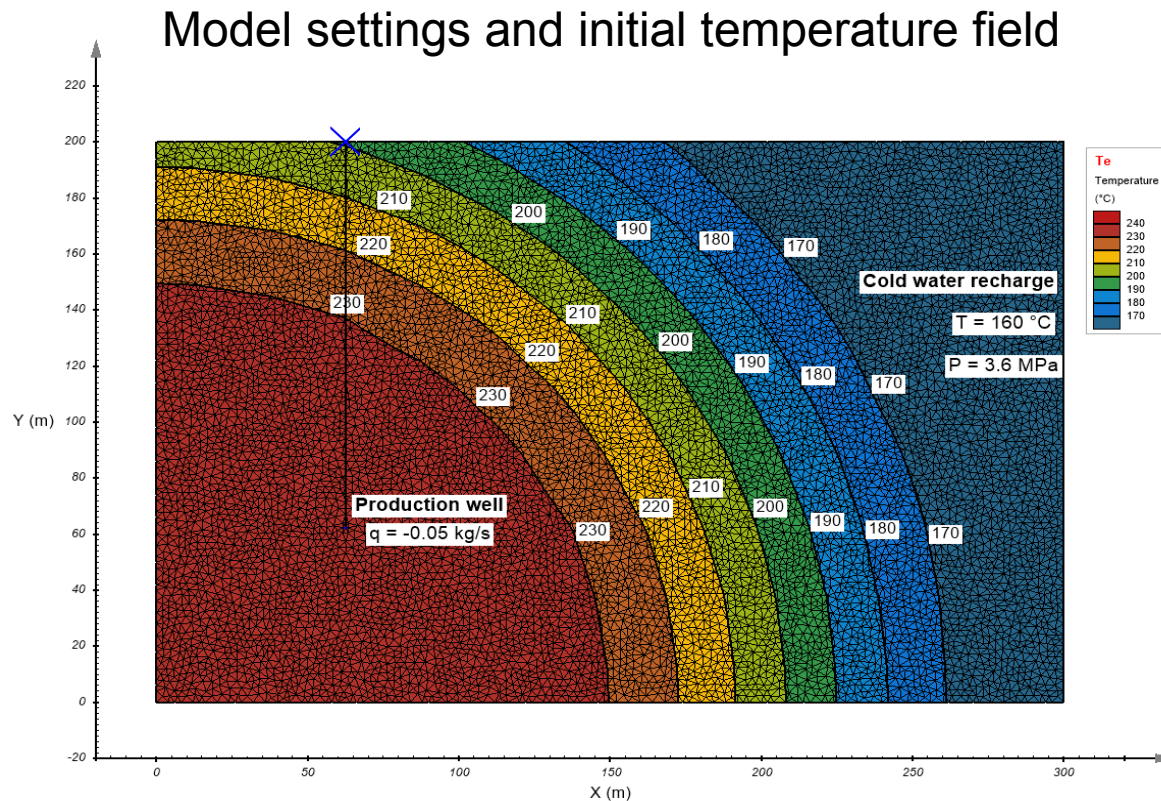
Yang et al. (2000)



2. Benchmarking

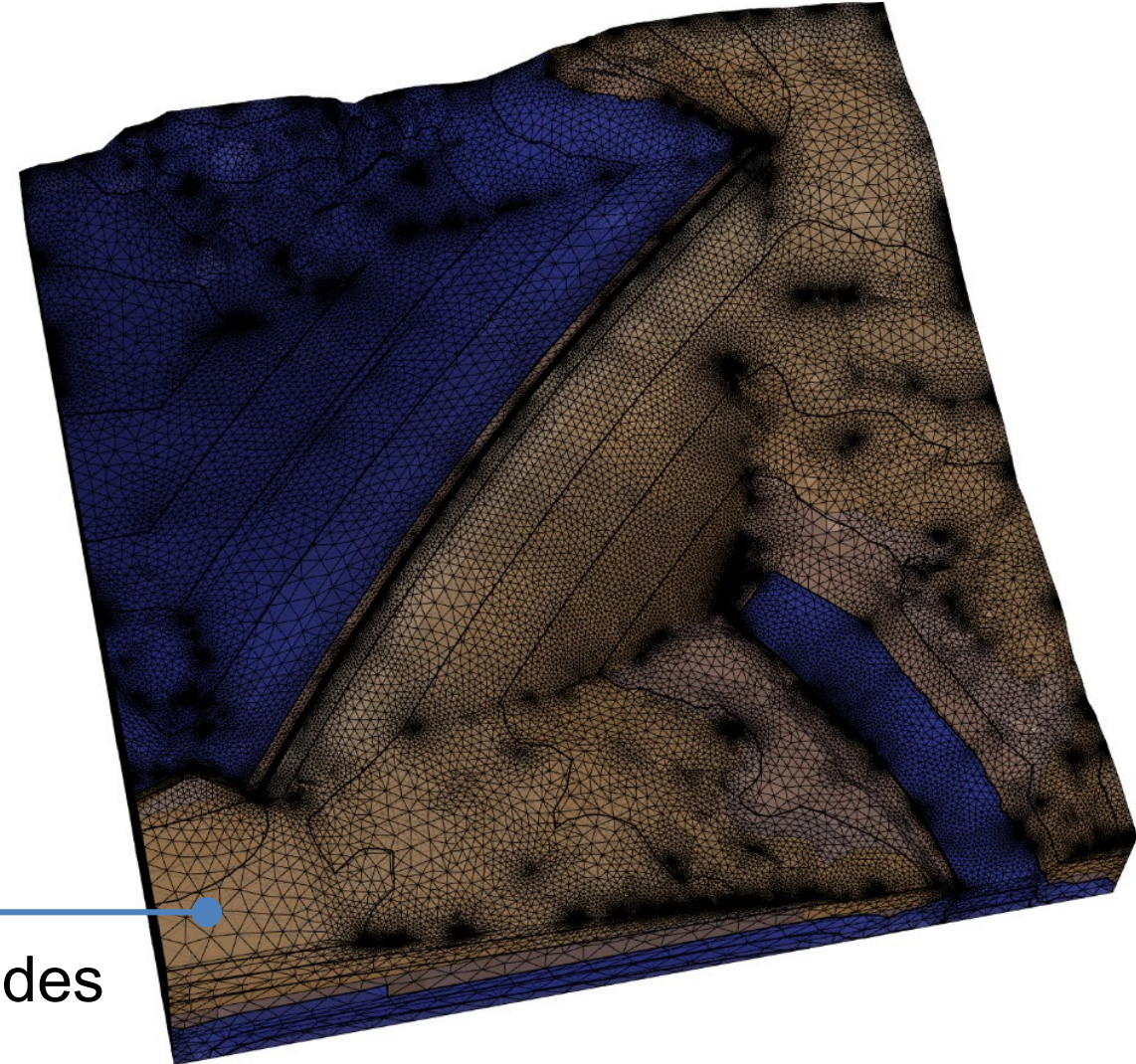
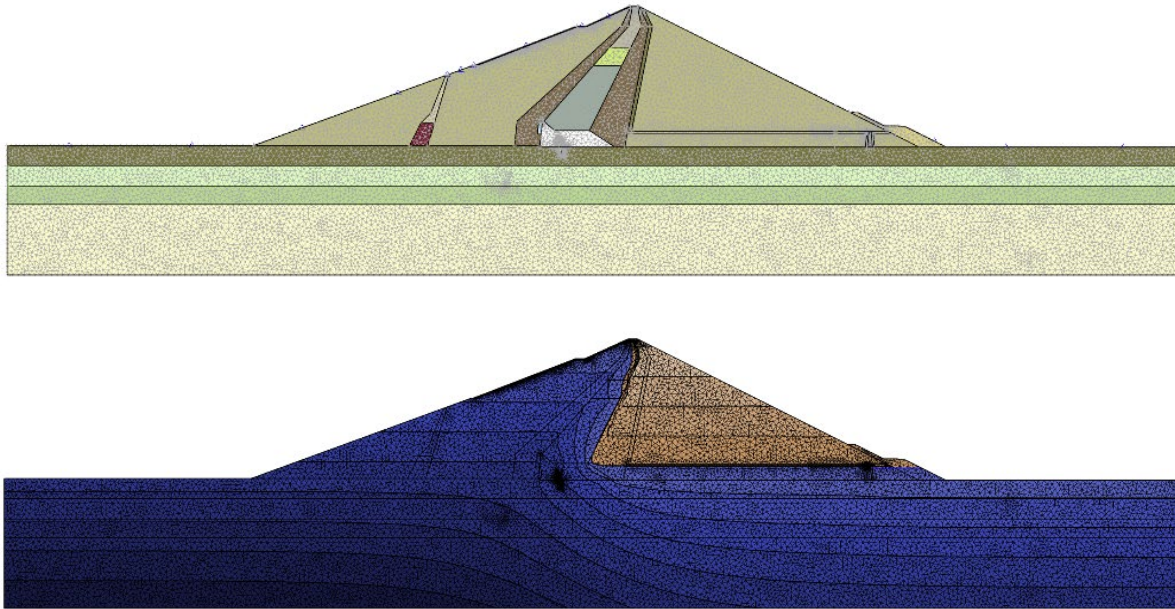
Non-isothermal geothermal modeling

- Case 4: Water-Vapor Multiphase Heat and Mass Transfer Problem



3. Ability to Model Field-Scale Systems

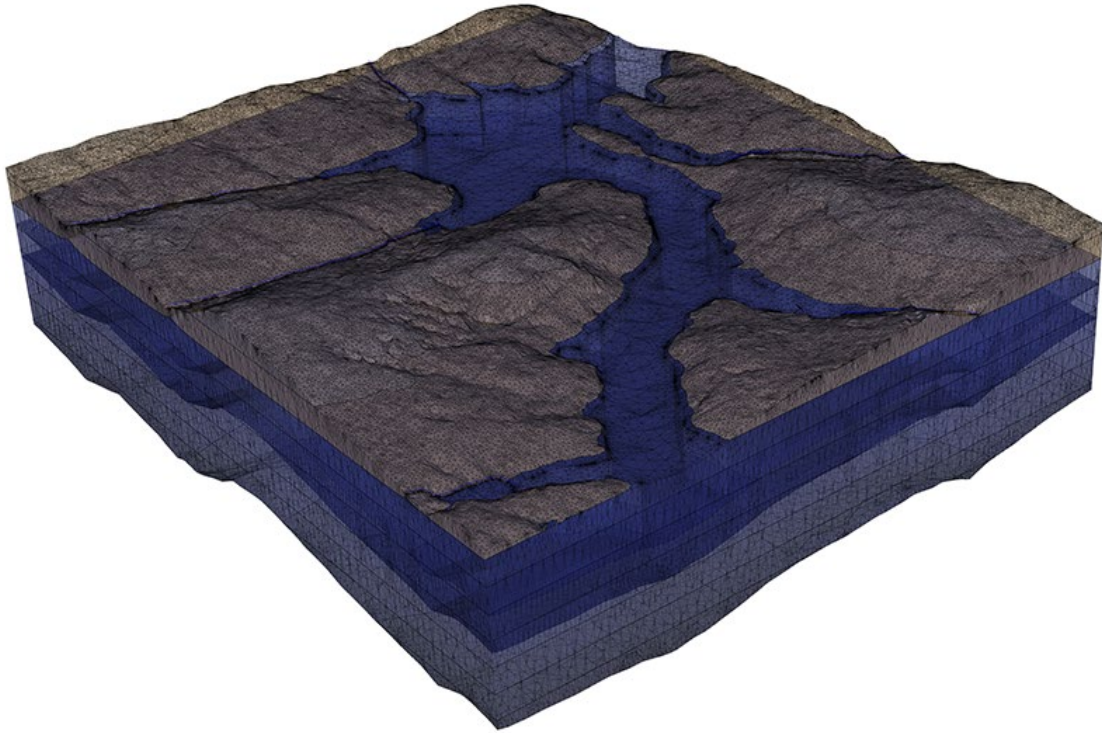
Complex Dam



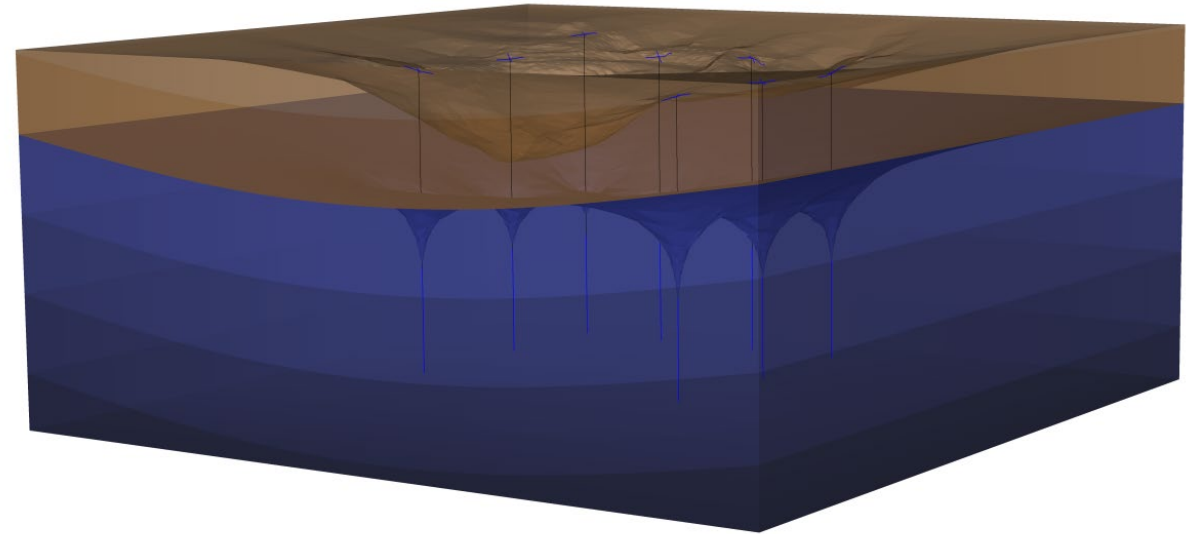
3D model: total 505,300 nodes

3. Ability to Model Field-Scale Systems

- Regional Flow



- Open Pit dewatering using pumping wells



4. Summary

- Los Alamos National Laboratory (LANL) has invested over 50 man-years of effort into the FEHM control volume finite element solver over the past number of decades. The code has been used on US EPA Superfund sites, low and high level nuclear waste sites, and a variety of fundamental hydrogeological applications.
- LANL and SoilVision Systems Ltd. have combined efforts to offer a groundwater and geothermal numerical modeling solutions of larger and more complex systems.
- ***SVOFFICE™ 5/WR***
 - ✓ Large Regional Models
 - ✓ Nonlinear Analysis
 - ✓ Handle Complex Geometry
 - ✓ NEW ***SVDESIGNER™*** Conceptual Modeling Module
 - ✓ Automatic Mesh Generation and Manual Refinement
 - ✓ Easy to Use
 - ✓ Import soil properties from the ***SVSOILS™*** database



4. References

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